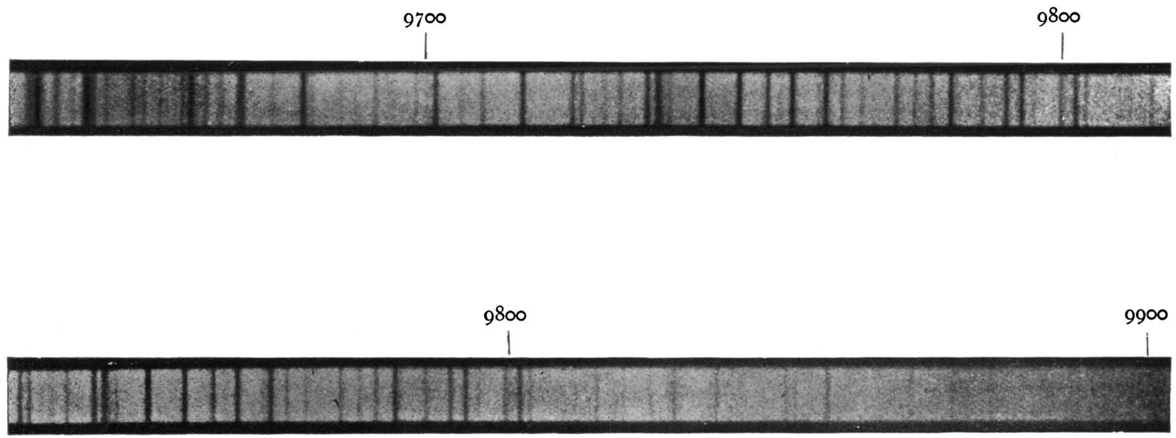

PLATE III. THE INFRA-RED SOLAR SPECTRUM. 9640 A TO 9900 A

THE SOLAR SPECTRUM IN THE REGION 9000 A TO 9900 A

By Keivin Burns

Beginning with the shortest wave-length which penetrates our atmosphere, about 2930 A, and extending to 9000 A, the solar spectrum has been well observed. The greater part of the lines in the spectrum have been identified as belonging to the various elements, or as due to the absorption of the Earth's atmosphere. Beyond 9000 A the solar spectrum has been photographed as far as 9600 A by Meggers[1] and as far as 9867 A by Abney[2], but no lines were identified by them. In this region beyond 9000 A the wave-lengths of the lines in the spectrum of iron and associated elements have been determined in the laboratory. Since these are the elements whose lines are most numerous in the better known part of the solar spectrum, it seemed that the lines due to these elements would be found also in the region of wave-lengths longer than 9000 A, and that the wave-lengths of all the solar lines in this region could be determined by means of them. This investigation was undertaken to identify as many solar lines as possible in this region; to measure the wave-lengths of all the lines by means of laboratory standards; and to separate the solar lines from those of terrestrial origin.

The 36-inch telescope and the spectrograph described by Campbell and Albrecht in *Lick Observatory Bulletin*, **6**, 11, 1910, were used for photographing the region beyond 9000 A. The photographic plates were Seed 23, sensitized by means of dicyanin furnished by the U. S. Bureau of Chemistry. The dye from the Bureau of Chemistry proved to be somewhat superior to the samples of foreign dye in my possession. In using dicyanin it is of considerable importance to have fresh dye, and the possibility of obtaining this dye in this country will be greatly appreciated by American spectroscopists.

The grating of the spectrograph is brilliant in the second order on one side, and this order was used for this investigation. The scale is about 10.5 A per millimeter, and the resolving power about 90,000. The aperture ratio of the camera is F8. The speed of this camera is so great that the exposure time in the red of the solar

[1] W. F. Meggers, *Ap. Jour.*, **47**, 1, 1918.
[2] W. de W. Abney, *Phil. Trans.*, **171**, 653, 1880.

spectrum (6600 A) is only a small fraction of a second; and yet the detail which may be observed in the spectrum is as great as in the case of any spectrograph which has ever been used for wave-lengths greater than 7600 A.

While the discovery of dicyanin has made it possible to observe a great extent of spectrum which could not otherwise be photographed, it may be of interest to consider the difficulties which are incident to work in this region. It should be remembered that the solar intensity drops rapidly with increasing wave-length, after passing the maximum in the green. And while dicyanin is a very valuable dye for use in the near infra-red, 7700A-9900A) its maximum sensitizing power is in the red, and it greatly decreases with increasing wave-length. Around 9800 A the necessary exposure time is 40 minutes, with the apparatus mentioned in this article. Using the same slit width, and screens of equal transparency to the region in question, the exposure would be only 2 minutes at 9100A; 35 seconds at 8400A; only 0.2 seconds at 6900 A and at Hα. It is seen from this that the combination of changing spectral energy and variation in sensitizing power of the dye makes the photographic intensity over ten thousand times as great in the red as it is in the region in which we are especially interested at present, namely, beyond 9000 A. Certain difficulties arising from this source will be mentioned later.

In observing by means of a grating it is usually necessary to take some precaution to eliminate the overlapping spectra of other orders. In the region which is commonly photographed in astronomical work, the overlapping orders can generally be avoided by the choice of a plate insensitive to the orders of greater wave-length, or by a screen which is nearly opaque to the orders of smaller wave-length. When we come to observe the infra-red in the second order the problem is not so simple. The third order red overlaps the second order infra-red which we wish to photograph, and we have seen above that the photographic action is over ten thousand times greater in the red than in the region we wish to study. The third order of the grating used in this work is about one-fourth as brilliant as the second for equal wave-lengths; consequently our screen must reduce the red by a factor of twenty or thirty thousand in order that it may not interfere with the second order spectrum. Usually a screen which reduces the higher orders by a factor of one hundred is entirely satisfactory, since the discrepancy in sensitivity

is seldom so very great in the region of spectrum which is ordinarily photographed. And a screen which transmits only one-hundredth of one per cent of the energy at a given wave-length is rated as opaque for that wave-length. We must have a different order of opacity in infra-red work, and no screen which I have examined transmits less than one ten-thousandth of every visible wave-length, if the screen is thin enough to transmit forty per cent of the energy at 9800 A. In practice, the overlapping green and blue light was absorbed by a screen of selenium red glass, and the red was eliminated by a cobalt blue glass and two Wratten B green filters. This combination of four screens reduced the intensity of the infra-red to about five per cent of that falling upon the first screen.

If the spectrum were being photographed in the first order it would be somewhat less difficult to remove the overlapping orders, as in that case the longest overlapping wave-length is only half that of the region under observation. But in either case there would be two other difficulties to be overcome in observing the region 9800 A, namely, scattered light and false spectra. These are just as bad in the first order as in the second. Light is scattered by imperfections in the glass of the lenses and by dust particles or miniature scratches on the surfaces of the lenses and grating. If this scattering amounts to one part in a thousand, it is evident that the stray light must be greatly reduced before the region 9800 A can be observed. Without a screen, the scattered light of wave-length 7600 A would blacken the plate as readily as the total light at 9900 A. However, when the third order has been eliminated as described above, the scattered light is not very noticeable in an hour's exposure.

The false spectra, or Lyman ghosts, are the source of the difficulty which is hardest to overcome. When light of a definite wave-length, such as sodium D light, falls upon a grating it is reflected or diffracted in certain definite directions which may be computed by a simple formula as a function of the wave-length. Substituting zero in this formula shows the position of the direct reflection; the number one gives the position of the first order; two gives the position of the second order; etc. A perfect grating would throw all of the light into the direct reflection and the various orders represented by whole numbers. In practice, however, a small part of the light is thrown into directions which correspond to fractions. For this reason we have light of wave-length about

7000 A and even 8000 A overlapping the region we wish to observe at 9800 A. And this will be true no matter what order we use. Now in the nature of the case, the nearer two wave-lengths are to each other, the harder it is to isolate them by means of screens. Since the sensitivity is hundreds of times greater at 8000 A than at 9800 A, it follows that a comparatively weak ghost (false spectrum) of the former wave-length may be very troublesome. The spectrum which could be photographed in the present investigation was limited by the presence of these false spectra rather than by the overlapping higher orders, scattered light, or waning sensitivity of the plate. Beyond 9900 A the screens at my disposal reduced the light of the desired wave-length too much in proportion to the reduction made in the false spectra, thus making the exposure times too great to be feasible. Undoubtedly in the near future a careful investigation of existing screens and the production of new ones will do more than anything else to advance the spectroscopy of the infra-red.

Plates were taken thruout the region 8900 A-9900 A, overlapping the known region by one hundred angstroms. I am indebted to Dr. Meggers for a manuscript copy of his paper which gives the wave-lengths and identifications of solar lines in the region 6500 A-9000 A. In the region 8900 A-9300 A the plate constants can be determined from the known lines of wave-length less than 9000 A. The wave-lengths in the unknown region 9000 A-9300 A, particularly in that part which adjoins the known region, can be found with some accuracy. However, this method of measurement did not lead to the identification of any solar lines with metallic lines which had been measured in the laboratory.

The fourth order, 4500 A-4650 A, is in fairly good focus when the spectrograph is adjusted for the second order in the region 9000 A-9300 A. The second and fourth orders in these regions of the solar spectrum were photographed side by side on the same plate, and the wave-lengths of the infra-red lines were determined by means of the known lines of shorter wave-length. The resulting values of the infra-red wave-lengths are not very exact; still they are accurate enough to show whether or not there are any solar lines which correspond in wave-length with the lines of iron and other elements which have been measured in the laboratory. In the case of the iron spectrum there is a line near the position of each strong iron line, but the intensities do not agree with the

laboratory results, and in order to consider these lines as due to iron it would be necessary to suppose the errors of measurement to be far greater than seems possible. In the case of the elements chromium, manganese, nickel, cobalt, vanadium and titanium, it is certain that their lines are too faint to be observed in this region without greater resolving power than 90,000.

In many cases these metallic lines may have been hidden by atmospheric (terrestrial) absorption lines, or blended with them. But in the majority of cases no line of intensity 00 on Rowland's scale is found in the neighborhood of the laboratory wave-length. These lines are no doubt present, but it will require greater resolution than 90,000 to show them, on account of their faintness. This is in keeping with what is known of the part of the solar spectrum which has already been observed. The absorption lines of the metals are very strong in the ultra-violet and violet, not so strong in the visible region, and weaker in the longer red and the infra-red. The strength of the telluric lines increases, on the other hand, with increasing wave-length, and the number of these lines also increases.

As the Sun is in fairly rapid rotation, the observed wave-lengths of the solar lines are shorter than normal at the east or approaching limb, and longer at the west or receding limb. The difference in wave-length for the two limbs amounts to 0.13 A. The telluric lines, on the contrary, have the same wave-length on all parts of the Sun and at all times, being due to our own atmosphere which has no motion with respect to the observer which can be detected by a displacement of spectral lines. This well-known effect of the Sun's rotation has been utilized by Dr. Meggers[3] to separate the lines of solar origin from those due to our atmosphere in the region 5800 A-9000 A.

In order to separate the two types of lines in the region 9000 A-9900 A, spectrograms of the east and west limbs of the Sun were obtained thruout the entire region. In the region 8960 A-9300 A two spectrograms of each limb were measured and the differences were taken. The mean error of a difference, east minus west, was found to be 0.04 A. If there had been any considerable number of solar lines present the differences would have clustered around two valves differing by 0.13 A. The differences fell pretty well on a probability curve whose center is at zero, as shown by lines of known

[3]Unpublished Ms.

terrestrial origin. Thruout the whole region plates of the east and west limbs were compared on the Hartmann spectrocomparator. Only three displacements were found, and these may be due to photographic effects. As a check on the accuracy of these comparisons a similar comparison was made of two plates in the region of 7600 A. The velocity shift was easily seen in the case of the stronger lines. It is likely that hazy lines and faint lines would not show the velocity shift with certainty. Beyond 9300 A the character of the observations deteriorates, so that the evidence in favor of the absence of solar lines is not so conclusive. It seems likely that in the region 9000 A-9250 A there are few, if any, lines of solar origin of intensity 0 or greater on Rowland's scale, and beyond 9250 A it is almost certain that all the strong lines are due to absorption in our own atmosphere. The region under discussion may always be of small interest, considered as the solar spectrum; but it is sure to be of interest in studying the absorption lines due to the gases of our own atmosphere. We cannot distinguish at present between the lines due to the various gases of the atmosphere. However, many lines have different intensities on different plates, and this suggests water vapor as their source. All the strong lines in the neighborhood of 9300 A show this variation.

The accompanying plate shows the spectrum beyond the region observed by Meggers.[4] The last few lines are of longer wavelengths than any observed by Abney[4]. The photograph has a very different appearance from that of Abney's diagram due to the presence of fainter lines on my plate, and the resolution of several groups which were seen as single lines by Abney.

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[4] *loc. cit.*